Testing adiabatic expansion of shocks in parsec-scale jets by dual-frequency VLBI experiments

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Abstract

We present results of simultaneous dual-frequency (2 and 8 GHz) VLBI observations of 12 active galactic nuclei with prominent jets. Spectral properties together with evolution of brightness temperatures in the jets are discussed. Measured sizes and brightness temperatures of VLBI features are found to be consistent with emission from relativistic shocks dominated by adiabatic losses. Jets with different regimes of magnetic field orientation to the local flow direction are demonstrated and discussed.

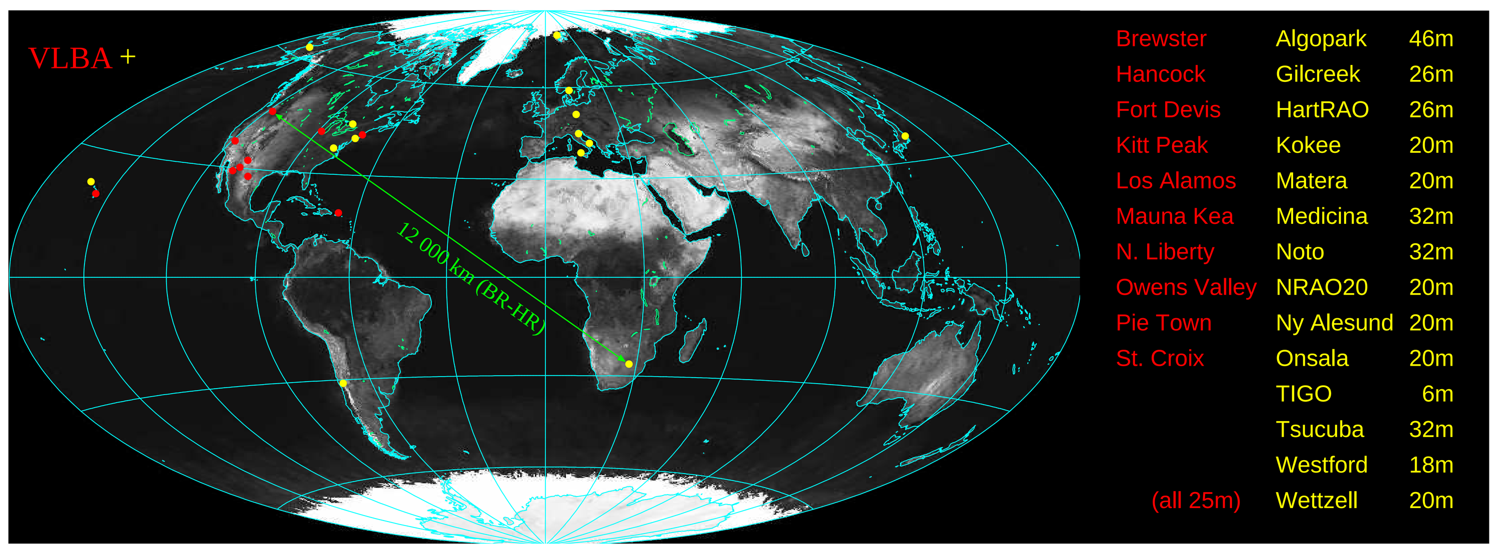


Fig. 1. Array of 10 VLBA antennas together with additional 14 stations. The maximum baseline projection between Brewster (USA) and HartRAO (South Africa) is close to the limit of earth-based VLBI.

Observations and Data Reduction

The observations were made simultaneously at 2.3 and 8.6 GHz with participation of all ten VLBA antennas and up to nine geodetic and EVN stations (Fig. 1) in framework of seven sessions of RDV (Research & Development – VLBA) long-term VLBI project. Four intermediate frequencies of 8 MHz wide each were recorded making up 32 MHz bandwidth with 16 spectral channels. The data were correlated at the VLBA correlator in Socorro with 4 sec integration time, and were calibrated in the NRAO Astronomical Image Processing System (AIPS) using the techniques adopted for subarrayed data sets. Phase correction for residual delays and delay rates was done using FRING with 4 min solution intervals and specifying a point-source model. Self-calibration and hybrid mapping as well as model fitting was performed in DIFMAP (Shepherd et al. 1994). In model fitting we used a minimum number of circular Gaussian components that being convolved with the restoring beam, reproduce the observed structure.

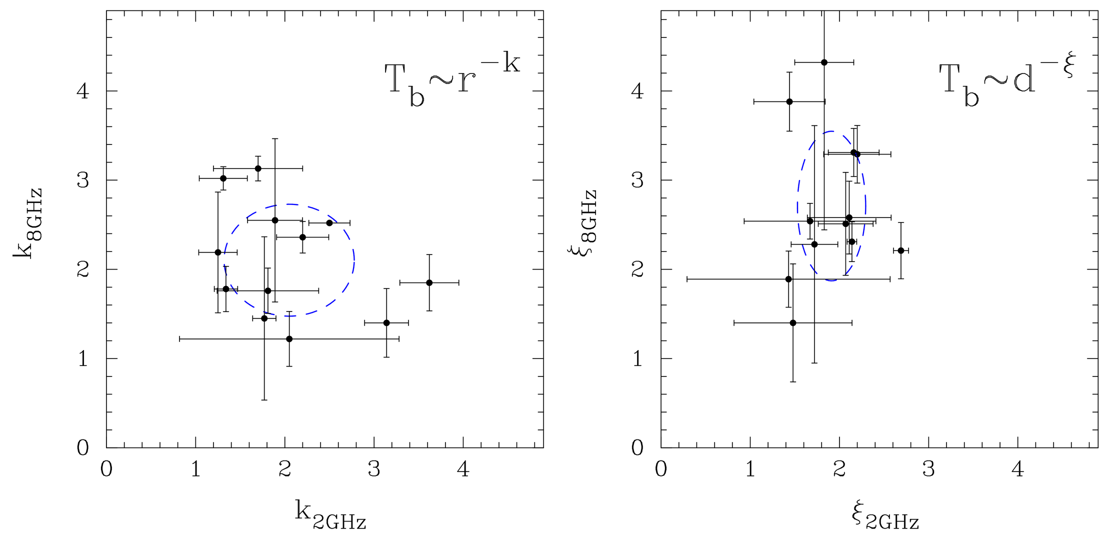
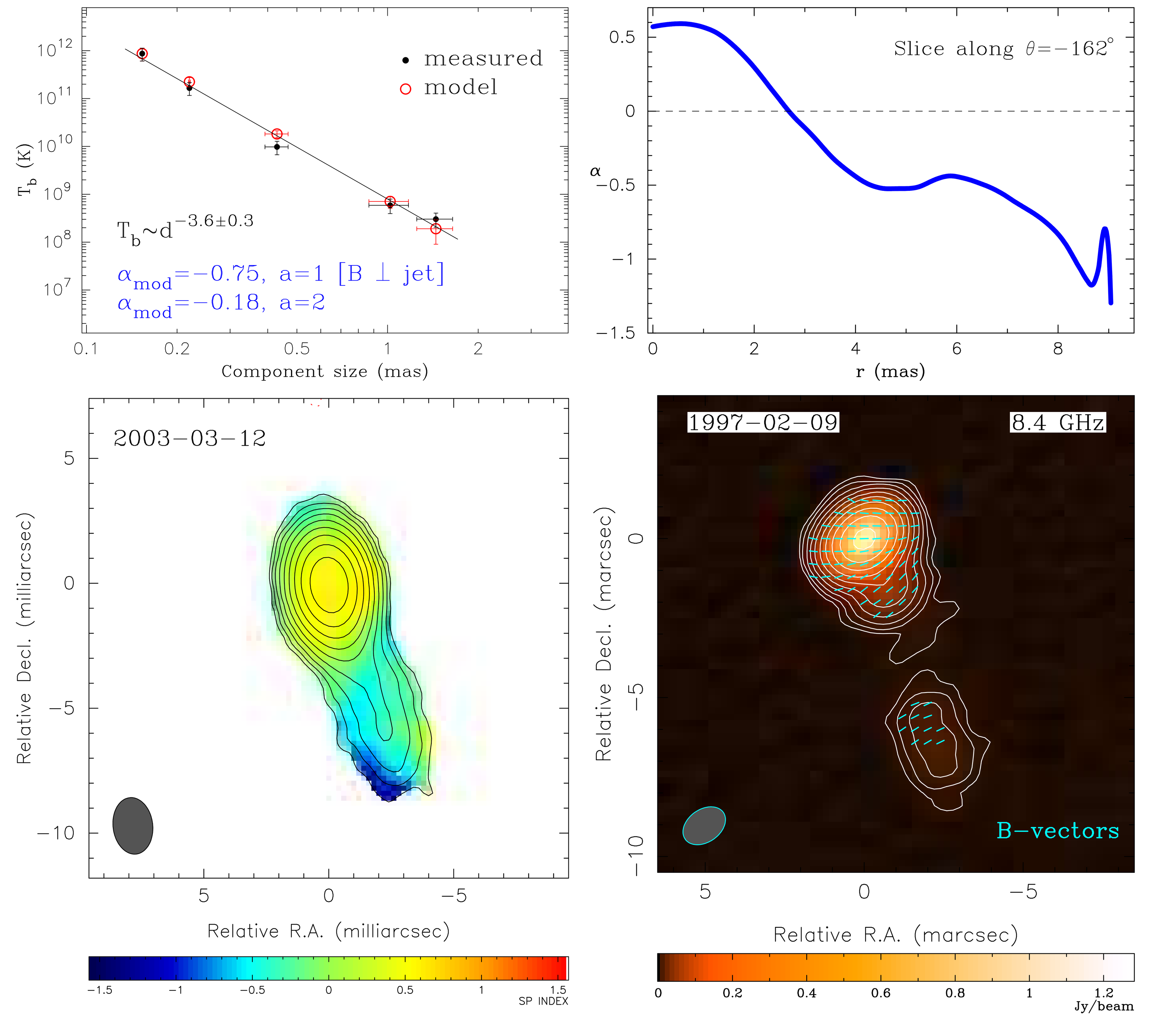


Fig. 2. Diagrams of power-law indices (line's slopes) of brightness temperature gradients with distance to the core (left) and with jet component size (right) at 2.3 and 8.6 GHz.

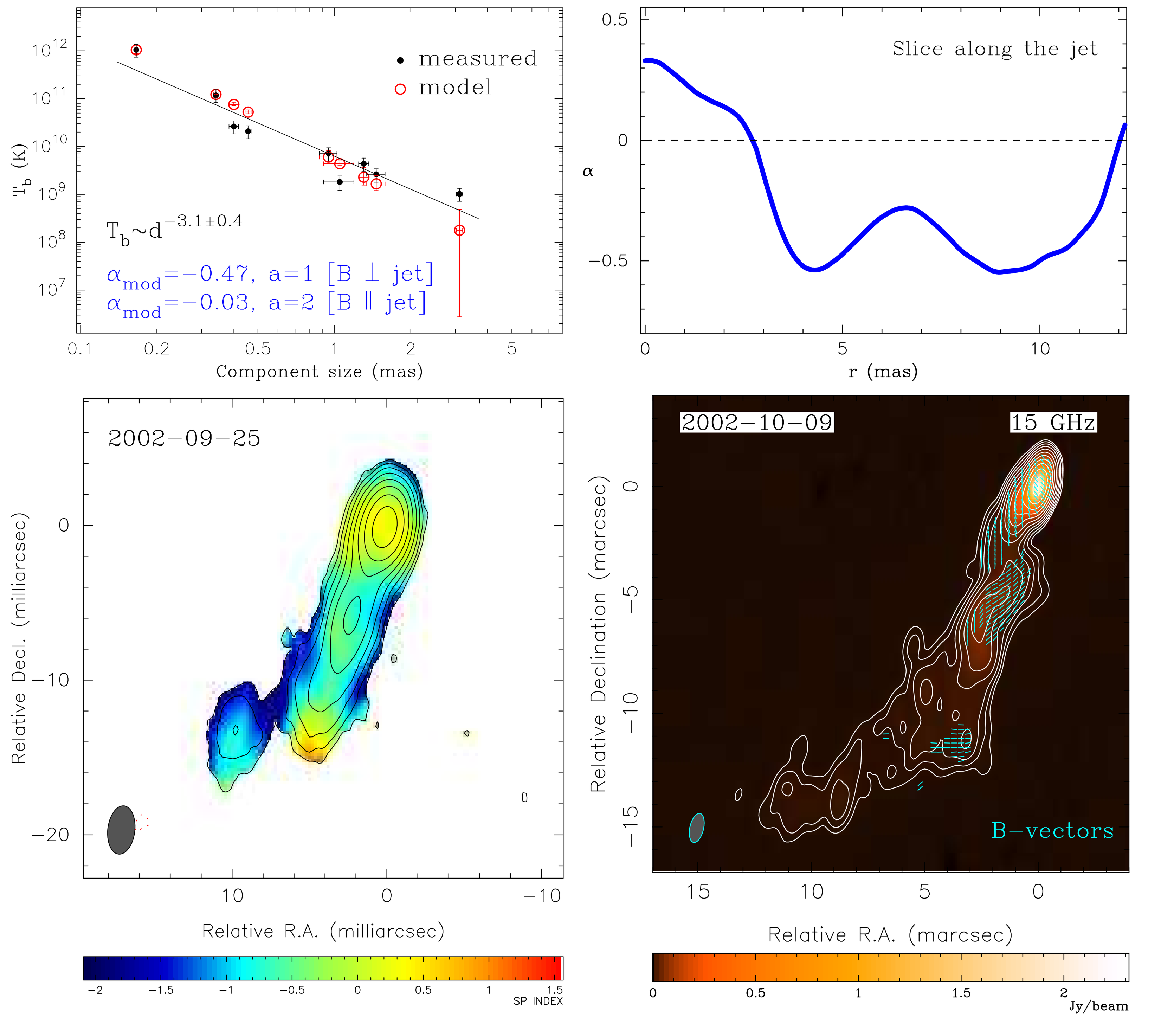
Discussion

We selected 12 active galactic nuclei (out of 222 observed in the RDV31-37 sessions) with prominent jets having at least 3 jet components at both frequencies for analyzing brightness temperature evolution as a function of (i) distance to VLBI core, r, (ii) size of jet component, d. Information of fluxes, sizes, and positions has been obtained from model fitting of self-calibrated data of each source. In both cases the dependencies can be described well with power law functions $T_\mathrm{b} \propto r^{-k}$ and $T_\mathrm{b} \propto d^{-\xi}$. The power law index k varies between 1.2 and 3.6 with the average value of $\overline{k}_{8\,\mathrm{GHz}} \approx \overline{k}_{2\,\mathrm{GHz}} \approx 2$. The power law index ξ varies between 1.4 and 4.3 with the average values of $\overline{\xi}_{8\,\mathrm{GHz}} = 2.7$ and $\overline{\xi}_{2\,\mathrm{GHz}} = 1.9$. Diagrams of fitted indices k and ξ are shown in Fig. 2.

1823+568 (BL Lac)



CTA 102 (Quasar)



The dependence of $T_\mathrm{b} \propto d^{-\xi}$ that also takes into account a VLBI core components may be used for testing a shock model suggested by Marscher (1990). In this model each of the jet component is an independent relativistic shock and emission is dominated by adiabatic energy losses. It is also postulated power law energy distribution $N(E)\,\mathrm{d}E \propto E^{-s}\,\mathrm{d}E$, and the magnetic field that evolves as $B \propto d^{-a}$, where d is a transverse jet size, a is an orientation parameter of magnetic field to local jet direction ($a=1$ in case of transverse orientation, $a=2$ for longitudinal orientation). We assume also the Doppler factor to be changing weakly within the detected jet. Then, as it is shown by Lobanov (2000) the model value of the brightness temperature of each jet component, $T_\mathrm{b,jet}$, can be related to the measured brightness temperature of the core (as an extreme end of the jet), $T_\mathrm{b,core}$, as $T_\mathrm{b,jet} = T_\mathrm{b,core}(d_\mathrm{jet}/d_\mathrm{core})^{-\xi}$, where d represents the measured sizes of the core and jet components, and $\xi = [2(2s+1)+3a(s+1)]/6$. Since spectral index $\alpha = (1-s)/2$, we obtain $\xi = a + 1 - \alpha(a+4/3)$. Now, having ξ determined from the data, we can test the shock model by

- comparing jet brightness temperatures predicted by the model with those from the data;
- choosing the appropriate pair (α_mod, $a=1$) or (α_mod, $a=2$) by comparing with observed jet spectral indices taken after applying core shift correction (Kovalev et al. 2008);
- for the final test we have used the results of VLBA polarisation observations where the magnetic field orientation is directly detected.

The results of such an analysis are presented here for BL Lac 1823+568 and a quasar CTA 102. In both cases the modeled brightness temperatures are consistent with measured values. The conclusion about perpendicular B-field orientation in 1823+568 is supported by polarisation map at 8.4 GHz (Pushkarev et al. 2008). In the quasar CTA 102 the shock model predicts that both orthogonal and parallel magnetic field orientations are possible, and it is confirmed by MOJAVE (Lister&Homan 2005) observations of this source. In the innermost part of the jet the magnetic field is transverse, while in more distant parts it is becoming longitudinal, implying dissipation of shocks and creation of polarisation sheath around the jet.

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